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BIOLOGY, HABITS, AND CONTROL OF THE WHITE-FIR SAWFLY (*NEODIPRION* SP.) IN WHITE FIR

By

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California Forest and Range Experiment Station
Division of Forest Insect Research
Berkeley, California

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TO : CHIEF, FOREST SERVICE

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FROM : GEORGE M. JEMISON, Director, By

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Enclosed are two copies of a recently completed report covering investigations conducted last season on the white-fir sawfly in second growth white fir stands. The sawfly infestation on the La Porte District, Plumas National Forest, provided the site for this study.

The work of Messrs. Struble and Lyon which is described in this report has provided us with a fairly comprehensive picture of the life history of the sawfly, and has yielded very worthwhile information on control by both artificial and natural methods. Of great interest is the role of a native polyhedrosis virus which was discovered in this study, and which seems to have brought the outbreak to an abrupt end. Thus, once again we have had a demonstration of the potency of a pathogenic organism in controlling a defoliator, which serves to emphasize the fact that we know all too little about natural control factors insofar as many of our forest insects are concerned.

Such evidence as was gathered in the study does not indicate that defoliation by the sawfly is an important factor as a cause of either tree mortality or growth reduction in white fir stands. It seems probable, however, that if the infestation had not been checked by natural factors this year, the picture would have been a good deal different.

Some additional observations are needed to round out knowledge gained on this problem. It is believed that the information necessary can be obtained this year without a great deal of additional investment. Subsequently, it is intended to publish the results of the study.

We are furnishing copies of subject report to all Stations and to a number of cooperating agencies directly concerned with the white-fir sawfly problem.

Enclosure

cc: All Stations

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The California Forest and Range Experiment Station is maintained in cooperation with the University of California at Berkeley, California.

California Forest and Range Experiment Station
Division of Forest Insect Research
Berkeley 1, California
February 17, 1954

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(NEODIPRION SP.) IN WHITE FIR

By George R. Struble and Robert L. Lyon

SUMMARY

Defoliation caused by outbreaks of the white-fir sawfly in white fir stands in several sections of California from 1951 to 1953 became of serious concern to timber growing interests in affected areas. A continuing epidemic in the Plumas National Forest early in 1953 provided an unusual opportunity to study this insect in detail as a basis for developing control strategy. Although native and known for over 40 years as a minor defoliator, the white-fir sawfly had not been previously studied and no details were available on its life cycle, habits, or control prior to this year. Detailed studies, conducted in 1953 at Howland Flat, Sierra County, an abandoned mining community, were successful in establishing pertinent facts with respect to stages of development, description of stages, habits, cycle of development, natural agencies of control, possibilities of direct control, and damage caused to host trees. The more important points determined are listed below.

1. Mating and oviposition takes place in the fall, late in October and early in November.

2. Eggs are laid in slits along the lateral edges of white fir needles, with only one per needle as a general rule. Here they overwinter and hatch in May or June, depending on seasonal temperatures.

3. The larvae develop to maturity in 4 to 5 weeks, during which they pass through 6 instars: the 6th or prepupal instar does not feed, but migrates to the soil and forms a cocoon. Here it remains in diapause until pupation and adult emergence 3 months to 15 months later.

4. Voracious feeding by masses of larvae in colonies numbering from 20 to 100 individuals caused complete defoliation of old growth foliage in 3 to 4 weeks.

5. Only old-growth foliage is fed upon; new, current-growth foliage is rarely attacked.

6. The black-headed, dark olive-green larvae respond to movement by wind or other factors by dropping. Many fall to the ground, then migrate back to crowns.

7. Biological control factors include predacious and parasitic insects, ants, birds, rodents and disease.

8. A disease caused by a native polyhedrosis virus broke out in epidemic form in July 1953, causing mortality to in excess of 90 percent of the maturing larval populations.

9. Weather factors, especially increased humidity, may influence the development and incidence of virus infections among larvae.

10. Aerial applications of DDT, conducted in cooperation with the Plumas National Forest, were very successful in controlling early stage larvae. Applications at a rate of 1 pound per acre to 80 acres of infested area killed about 99 percent of the population.

11. The European pine sawfly virus was non-infective to the white-fir sawfly in laboratory and field tests conducted with water suspension. This virus was sent to Berkeley from New Haven, Connecticut. It was applied by the Department of Biological Control, University of California.

12. Although incomplete, studies of the damage to stands by sawflies revealed about 10 percent mortality and considerable topkilling among the suppressed and intermediate tree groups, but there was no permanent damage indicated in more vigorous trees. No evidence of lowered growth rate was revealed in studies of increment cores from defoliated trees but it is expected that this will show up within the next 5 years.

INTRODUCTION

The white-fir sawfly, Neodiprion sp. (Diprionidae) has been known as a defoliator in white fir, Abies concolor (Gord. & Glend.) Lindl. for over 40 years in the California region. It was first collected from Yosemite National Park in 1910 by H. E. Burke. Since then, records on file at Berkeley reveal that this insect has been taken by forest entomologists and others from several different portions of the Sierra Nevada Mountains from Mariposa County northward . Reported local damage indicated little more than a temporary slowing in growth rate. The relative insignificance of this insect as an economic pest was such that it was not included in the recent revision of Bulletin 273 by F. P. Keen (1). Specific identity is yet to be determined.

Between 1950 and 1953, this hitherto minor insect species became epidemic in several localities from the Central Sierras to the North Warner Mountains. The heaviest center of activity was in second growth stands in the Plumas National Forest near Howland Flat and Whiskey Diggins (2), ghost towns of early mining days. Old-growth stands in Yosemite National Park were severely hit. The resultant damage and threatened killing in about 12,000 acres of old and second-growth white fir gave just cause for concern by owners and managers of affected timber, and emphasized the need for information as a basis upon which to judge the necessity for control or methods to be employed.

Preliminary observations in the fall, 1952, on the extent and character of defoliation and insect habits, were followed subsequently the next spring and summer by detailed observations, records and experiments. This investigation was centered at Howland Flat, Sierra County at elevations ranging from 5,000 to 7,000 feet. Supplementary studies and observations were continued at Berkeley, California and in Yosemite National Park. Studies on the possibility of introducing virus infections[1], and in determining the occurrence and pathogenicity of native infections were conducted in cooperation with the Biological Control Laboratory, University of California[2], and the New Haven, Connecticut Forest Insect Laboratory.

The results of this investigative work on (1) the biology and habits of the fir sawfly; (2) the natural control factors involved in keeping it in check; (3) the use and application of aerial DDT sprays are presented here in detail as a report of progress.

HOST TREES AFFECTED

White fir, Abies concolor, is the primary host tree of the white-fir sawfly. Defoliations occur infrequently in red fir, Abies magnifica, A. Murr. growing under infested white firs where less severe infestations result when immature larvae drop onto understory trees. On occasion affected red fir are stripped completely; trees growing amongst but not beneath or touching white fir are unaffected. Other host trees occurring in admixture with infested white fir include Douglas-fir, Pseudotsugae menziesii (Mirb.) Franco and four pine species none of which are affected.

CHARACTER OF STANDS DEFOLIATED

Epidemic populations of this sawfly occur characteristically in rather dense contiguous bodies of timber. Heaviest infestations including the entire crown are found among the understory, intermediate and suppressed trees and some of the codominants. Mid- and basal crowns of dominants are heavily defoliated, and occasionally 80 to 90 percent of the crown foliage of these trees is destroyed. Open bodies of timber are relatively free from infestation.

In the Howland Flat area, all infested stands were closed, with gaps of scattered uninfested trees in between. (Photo 1). Here defoliations in 1952 varied from an estimated 15 percent to 100 percent of the crown, with an average of between 70 and 90 percent. (Photo 2.) The shock of defoliation was so great among approximately 10 percent of the trees that no recovery was evident in 1953. Top-killing was very common. An additional shock in 1952 was brought on by a mid-

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1/ Neodiprion sertifer virus polyhedra sent by P B. Dowden, New Haven, Conn.

2/ Field applications and checking of N. sertifer virus and determination of native polyhedrosis virus by C. G. Thompson, University of California.

summer freeze which killed all of the new growth foliage. The 1953 defoliations were somewhat less serious, and partial recovery was effected by weather conditions favoring the growth of new foliage.

The infested stands in Yosemite National Park were all in contiguous bodies of uneven aged virgin mixed conifer species. Most seriously defoliated were the understory white fir, especially the intermediate and suppressed trees, as well as poles and reproduction. Small bodies of reproduction and poles in openings were much less seriously affected.

THE INSECT

Description of Stages (Figure A)

Adults

1. Males: Length - 5 to 6 mm; slender body, pectinate 21-segmented antennae. Color - antennae, head, thorax and abdomen dark brown; mouth parts, legs, and tarsi light yellowish brown.

2. Females: Length - 6 to 8 mm; thick body, serrate 21-segmented antennae. Color - Antennae, compound eyes, ocelli and mandibles dark brown to black; scutum with one large lateral dark brown bar each side; remaining portion of head thorax and appendages light yellowish brown; abdomen turquoise or light yellowish brown, depending on distension by eggs.

Eggs. Color - turquoise green, slightly lighter than fir needle color, and turning light gray or off-white with full embryo development. Shape: laterally, crescent; dorsally, cigar-shaped. Size: length, 1-1/2 mm; width, 1/3 mm. Texture: surface wrinkled and fragile, becoming smooth and swollen with embryonic development.

Larvae.

1. Color: Olive green bodies in all except the 6th instar, with shade variations from dark toward lighter as each stadium is completed; appearance of median dorsal line in third instar, two lateral lines in addition in fourth and fifth instars, and widening of lateral lines in sixth instar, with occurrence of two close fine dorsal lines; head in all instars except the sixth cream color at first, and turning black immediately; in sixth or prepupal instar head remains cream color with black simple eyes and dark brown mouth parts.

2. Approximate size and duration of instars: first, 3-5 mm, 5 days; second, 6-8 mm, 5 days; third, 10-13 mm, 4 days; fourth, 16-20 mm, 4 days; fifth, 25-29 mm, 6 days; sixth, 20-25 mm, prepupal, non-feeding.

Cocoon. The cocoon is formed by the prepupal larvae, and serves to shelter this stage in varying periods of diapause, and the subsequent pupal stage to emergence of adults. It is a tough, fibrous, ovoid-cylindrical case, varying in length from 5 to 8 mm. long and about 3 mm. wide. Its color when first formed is silver,

turning to golden brown later on. More often cocoons are found within the soil immediately underlying the duff, but occasionally cocoons are found on the duff surface or sometimes attached to green foliage.

Habits: Adult flight and mating. Emergence, mating, flight, and oviposition occur during a relatively short period late in the fall. In 1952 these events took place from October 23 to November 3; in 1953 they were about 10 days later. After emergence from the cocoon the adults may remain in the moist soil or emerge rapidly to the surface, depending evidently on ground temperatures. The emergence of epidemic numbers in the fall, 1952 resulted in a distinctly audible buzzing sound near the ground.

Mating behavior was not observed. Among the countless numbers of adults on the ground immediately subsequent to emergence in 1952, there was no evidence of mating. Both males and females were observed to take flight as soon as wings became dry and straightened. It is assumed that this habit takes place during flight amongst the crowns of trees, on the basis of observations of males hovering close to females which had alighted on twigs.

Number and location of eggs: The number of eggs deposited by a single female varies considerably. Dissections made of six gravid unfertilized females revealed 403 eggs, averaging 67 per female, with variations from 53 to 83.

It is probable that most of the eggs contained within a female ovary are deposited, as judged from field counts of eggs in foliage. A total of over 16,000 eggs from 161 six-inch twigs, each containing 15 laterals, taken at random from 104 trees revealed an average number per twig of 40 and a maximum number of 471 eggs. It is probable that the larger numbers of eggs per twig resulted from ovipositing by several females.

The eggs are deposited in a slit beneath the epidermis along the lateral edge of the needles. Examinations made in June 1952 from 10 six-inch twigs having a total of 4520 eggs revealed a preference on the part of the females for newer foliage since 3085 or 68 percent of the eggs were deposited in 1951 foliage; 1170 or 26 percent in 1950 foliage; 232 or 5 percent in 1949 foliage; and 32 or 1 percent in older foliage.

Limited data indicates that the number of eggs deposited varies with the crown height above ground. Counts from one six inch tree felled and examined revealed an average number of 5 eggs per twig lateral among 89 laterals taken from the basal crown, 20 eggs per lateral among 101 mid-crown laterals, and 40 eggs per lateral among 90 top laterals. In this instance 8 times as many eggs were deposited in the top as in the basal crown, and 4 times as many in the mid-crown as in the base.

As a general rule, only one egg is deposited in a single needle. Less than 5 percent of all needles examined contained more than one egg. Among those needles containing more than one egg, two eggs were common and four, the maximum number found, were rare.

Egg Viability and Hatching: Among 1400 eggs examined, 1391 or 93 percent were viable. Failure of the remaining unhatched eggs was due primarily to dessication. These determinations are based on examinations of 1000 empty chorions in needles taken from random field samples and rearings from needle-infested twigs placed in water.

The period of hatch in 1953 was between June 6 and July 5, with earliest hatch at lower elevations (5200 feet) and latest hatch at higher elevations (7,000 feet). All samples included heights varying from ground level to 12 feet.

Larval Ecdycis and Feeding Habits: In the younger instars, the larvae orient themselves perpendicularly to the axis of needles with the anterior body portions projecting out over the edge; the older instars curl themselves around the needle with convulsive movements for several seconds to a minute. The dorsal integument of the thorax splits, followed by a 3-way split of the head capsule.

Gregarious feeding is characteristic of the first five instars, while there is no feeding in the sixth or final instar. (Photo 3.) The heads are always oriented toward the apex of needles while feeding. (Photo 4.) Mass feeding by frequently over 20 first and second stage larvae and six to ten fourth and fifth stage larvae per needle, continues from the apex toward the base. All larvae occur in colonies of 30 or less to over 100 individuals. (Photo 5.)

The initial feeding is primarily in the youngest of the older foliage. Often the first feeding is in 2-year-old needles despite the location of eggs in younger foliage. The feeding in 1953 started mostly in 1951 foliage, with subsequent feeding continued progressively in the older foliage. This was due to the complete absence of 1952 foliage which was destroyed by a mid-summer freeze. Feeding in new-growth (1953) foliage was observed only once during hundreds of observations.

This gregarious feeding habit results in the destruction of leaf tissue in varying amounts up to all except a central core of each needle. (Photo 6.) Affected foliage soon dies, turning yellowish to reddish brown. Evidence of infestations is clearly visible within one to two weeks after eggs have hatched, and within three to four weeks defoliated trees with skeletonized yellowish brown needles take on a lace-like appearance. (Photo 7.)

Amount of Frass Deposited: The relative amount of frass resulting from feeding by the different larval instars to and including the 4th instar is shown in Table 1. This is believed to typify the voraciousness and destructive capacity of the 1953 colonies. This information resulted from weekly collections from one 30 X 36-inch muslin catch frame placed directly beneath the crown of a single tree. Each collection represented the total deposit by an unknown number of larval colonies above. No change in relative numbers of larvae was noted during the measurement period. Frass identity by larval instars was judged on the basis of pellet size compared with known pellets from the different larval instars.

Table 1. Frass Deposited by Different Larval Instars

Date 1953	Instar	Amount of Frass Deposited	
		cc	% of total
June 30	1st	1.2	0.3
July 7	2nd	38.3	10.6
" 14	3rd	220.8	61.3
" 21	4th/5th	99.7	27.7
" 28	5th	0.4	0.1
	Total	360.4	100.0

The sudden drop in frass deposit by 4th and 5th instar larvae was coincident with the appearance of an epidemic virus infection which will be discussed later.

Migration or Dropping of Larvae: The behavior of immature colonies with respect to mass movement, especially in the fourth and fifth instars is the result of a response to sudden jarring or vigorous swaying of branches by wind, animals, or birds. These stages tend to move rapidly to stem areas, but the more common habit is to drop. Many of the larvae fall to the lower branches, and great numbers to the ground, then migrate back up the trunk and into the lower crown foliage. Mass migrations of returning larvae are common; in some cases observed the returning larvae obscured completely the basal trunk area.

This habit has a distinct bearing on the character of defoliations among the crowns of a stand. The heavier defoliations in mid- and basal-crowns of the taller infested trees, in contrast to more uniformly complete defoliations in all crown areas of understory trees is most logically accounted for by differences resulting from wind disturbance. The more vigorous movement of taller crowns causes the larvae to drop, whereas crown movement is insufficient in the understory to stimulate appreciable dropping.

The first three instars are relatively quiescent during branch movement. Second and third instars respond by vigorously swaying the head and thoracic portions of the body and often by moving backward toward the stems, but they seldom drop.

Sixth instar larvae are rarely found among maturing colonies. Many of the mature fifth instar larvae, and most of the new sixth instar larvae, drop to the ground. Very few of either stage may be seen migrating downward. On the ground most of the newly formed sixth instar larvae originating from freshly molted or dropped individuals, enter the soil immediately overlain by duff, and form cocoons 3/.

3/ In the fall, 1952, cocoons from epidemic populations were so common on the duff surface that it was possible to gather handfuls at a time. This was evidently a response stimulated by overcrowding.

Prepupae

This stage remains quiescent within the cocoon for varying periods before pupation. Individuals completing development to adults in late October pupate within 45 to 70 days; those that go into an extended diapause remain quiescent for a period of approximately 400 days before pupation. The percentage of prepupal larvae completing development through pupae to adults the same season, or of those remaining in extended diapause has not been determined. However, evidence based on an extremely heavy emergence in the fall, 1952, suggests strongly that those remaining in extended diapause constitute a great minority.

NATURAL CONTROL

Predation

Insects: Coccinellids (Coleoptera) in adult and larval stages were most common among the insect predators. Two genera with one species each were represented. These have been identified by the U. S. National Museum as Anatis rathvoni Lec., a very large coccinellid, and Neomysia subvittata (Muls.) which is somewhat smaller. The first mentioned species was much the commoner of the two, and both the adult and larval stages were observed repeatedly to be voracious feeders on sawfly larvae.

An hemipterous predator identified as Nabis alternatus Parshley (Nabidae) was observed feeding on sawfly larvae, but was not common.

Ants of various species were observed commonly carrying away and feeding upon sawfly larvae, especially on those which had fallen to the ground. They were seen so often in fact, that the control exerted by them is believed to be of some significance.

Jerusalem crickets, Stenopelmatus longispimus Brunner were found in the soil preying on sawfly cocoons. Even one of these large insects may account for the destruction of large numbers of sawfly cocoons. Other soil-inhabiting, predacious insects believed to feed on sawfly prepupal larvae in cocoons included numerous large dipterous larvae of the family Dolichopodidae, and neuropteron raphidid larvae.

Birds: Grosbeaks were observed foraging from branch to branch among thickly grouped masses of larvae, causing hundreds of them to drop to the ground. These birds are common, and undoubtedly are responsible for a large larval drop in addition to actual predation. The only other birds seen foraging among infested white fir branches were small and gray, about the size and general character of chickadees.

Mammals: Chipmunks were the only mammals observed feeding, mostly on larvae which had fallen to the ground.

Parasitism

Eggs: No evidence of parasitism was found among 1,400 eggs checked for this purpose. Viability was very high, with only 7 percent hatching failures which were attributed to desiccation.

Larvae: Parasitism by natural insect enemies was observed to take place among the sawfly 5th and 6th or prepupal instars prior to cocooning. The parasites seen most often in the act of oviposition on these larvae were larvaevorids (Diptera). These were most often observed on the ground in search of the mature larvae. In a few instances the act of oviposition was observed as well as the parasite eggs located externally on the dorsal thoracic body portion of the sawfly larva.

Ichneumonid (Hymenoptera) parasites were numerous among the trees and close to the ground, but none was seen in the act of oviposition. In a few instances parasite eggs were found on 5th instar larvae. Nineteen different kinds of Ichneumonid parasites were collected in flight, and these have been identified by National Museum specialists (Table 2).

Parasites reared from 1952 season cocoons taken from the soil revealed that pteromalids (Hymenoptera) outnumbered by far all other parasitic insects. As an example, among 100 parasitized cocoons placed in rearing there emerged: pteromalids Tritneptis Klugii (Ratz.) 4/--981; ichneumonids--6; larvaevorids (Diptera) cleptids--1; (Hymenoptera)--1; bombyliids (Diptera)--1; total--990. The same relative number and kinds of parasites were reared from 4 other lots of cocoons taken from different locations.

The great numerical superiority of the pteromalids is due in part to multiple parasitism and in part to higher incidence in occurrence. This was the only parasite among those reared which yielded more than one individual per cocoon. The average number per cocoon was 25, with some cocoons yielding close to 40 individuals. Only one parasite adult per cocoon emerged among the other species taken.

The effectiveness of any single species or of the total of all parasites combined was not determined. Their influence on populations in 1952 and 1953, however, was not observable. Some idea of the incidence of parasites among larvae in lengthy diapause, which overwintered in 1952-1953, was obtained. Dissection of 50 cocoons revealed only 9 unaffected larvae, or a parasitism of 82 percent. This record serves only as an indication of high parasitism among prepupal larvae in late diapause.

The different species of parasites, predators, and associates of the white-fir

4/ This is one of the 3 most abundant parasites of the larch sawfly in Minnesota. (3)

sawfly have been identified insofar as possibl_ by specialists 5/ of the National Museum. These are listed below in Table 2, according to their relationship with the sawfly.

Table 2. Parasites, predators, and associates of the white-fir sawfly

Designation	Order	Family	Genus Species
		Parasites Reared from Cocoons	
Hopk. U.S.			
33931-A.I	Hymenoptera	Ichneumonidae	Exenterus tsugae Cush.
B.D.J.			Lamachus sp.
E			Bathytrix areolaris (Cush)
			Bathytrix sp.
F,O.L			Opidnus sp. nr. tsugae (Cush.)
L			Endasys subclavatus (Say)
G,K,M			Ischnus sp. nr. oregonensis Cush.
G			Trychosis sp.
H,N			Gelis sp.
P		Pteromalidae	Tritneptis klugii (Ratz.)
C		Cleptidae	Cleptes purpurata Cr.
Q,R,S,T	Diptera	Larvaevoridae	Phorocera sp. nr. hamata A&W
U		Bombyliidae	Undetermined
		Predators of Larvae	
33932-E	Hemiptera	Nabidae	Nabis alternatus Parshley
D	Coleoptera	Melyridae	Undetermined
C		Cantharidae	"
A		Coccinellidae	Anatis rathvoni Lec.
B			Neomysia subvittata (Muls.)
		Predacious Associates of Larvae	
33936-A	Coleoptera	Coccinellidae	Adalia bipunctata var. quadrimaculata (Scop.)
B		Cleridae	Cymatodera ovipennis Spin.
		Parasitic Associates of Larvae	
33935-Q	Diptera	Larvaevoridae	Xanthophyto sp. probably labis (Coq.
A	Hymenoptera	Ichneumonidae	Near Stilphus but not that genus
D			Cryptus mutatus Pratt
H			Near Cubocephalus
F			Scambus sp.

5/ Specialists: R. H. Arnet, B. D. Burks, E. A. Chapin, K. V. Krombein, C. F. W. Meusebeck, R. I. Sailer, L. M. Walkley, L. H. Weld, W. W. Wirth

Table 2 (Cont'd)

Designation	Order	Family	Genus	Species
33935-G			*Itoplectus*	sp.
C			? *Ephialtes*	sp.
B			? *Campoplex*	sp.
I			*Aoplus*	*velox* (Cress.)
A			? *Dicaelotus*	sp.
E			*Euceros*	sp. nr. *fasciens* Davis
J		Braconidae	*Blacus*	sp.*
K			*Euphorus*	*pallipes* (Curt.)*
L			*Aphidius*	*nigripes* Ashm.*
N			*Apanteles*	(2 spp.)*
O	Hymenoptera	Braconidae	Undetermined*	
M		Figididae	*Melanips*	sp.
P		Pteromalidae	*Amblymerus*	sp.

*Not sawfly parasites according to C.F.W. Meusebeck

Insect Associates

Designation	Order	Family	Genus	Species
33934-A	Coleoptera	Elateridae	*Ctenicera*	*hieroglyphicus* Say
33933-Z_1	Diptera	Agromyzidae	*Phytobia*	sp.
Z_2			*Cerodontha*	*denticornis* (Panzer)
A,B		Muscidae	*Hylemya*	*cilicrura* (Rond.)
A			*Paregle*	*cinerella* (Fall.)
J		Heleomyzidae	*Pseudoleria*	*pectinata* (Lw.)
			Tephrochlamys	*canescens* (Mg.)
S			*Eccoptometa*	*simplex* Coq.
G		Scopeumatidae	*Scopeuma*	*stercorarium* (L.)
T		Lauxaniidae	*Minettia*	sp.
Y		Chamaemyiidae	*Leucopis*	sp.
E,Z_3Z_4		Lycoriidae	*Bradysia*	sp.
F		Bibionidae	*Bibio*	*slossonae* Cock.
I			*Bibio*	*Xanthopus* Wied.
U			*Philia*	sp.
K,M,W		Fungivoridae	Undetermined	
O,L		Heleidae	*Forcipomyia*	*cilipes* Coq.
C,D,E,X		Tendipedidae	Undetermined	
P		Drosophilidae	*Scaptomyza*	*nigrita* Wh.
N		Phoridae	*Megaselia*	spp.
Q,Z		Empididae	Undetermined	
U		Bombyliidae	Undetermined	
H		Syrphidae	*Metasyrphus*	sp.
R			*Melanostoma*	sp.

Table 2 (Cont'd)

Designation	Order	Family	Genus	Species
		Sawflies		
33930-B,K	Hymenoptera	Xyelidae	Pieroneura	sp.
C			Xyelecia	nearctica Ross.
D,E,F,G		Pamphiliidae	Acantholyda	sp.
H		Tenthredinidae	Nematus	sp.
I			Periclista	sp.
J			Tenthredo	sp.

Disease

The possibility of occurrence of a native disease as a control factor in this sawfly outbreak was one of the major considerations in this study. Consequently a constant lookout was maintained, from the eggs through the different larval instars, for the presence and extent of disease. Extremely high populations of eggs present in the spring of 1953 indicated that epidemic larval populations were again in prospect. This, in turn, suggested the possibility of disease infection, commonly found among epidemic populations of other species of hymenopterous, as well as lepidopterous defoliators.

The first evidence of disease infection was noted by the co-author among 4th and 5th instar larvae on July 13th, near the 5,000 foot elevation level $1\frac{1}{2}$ miles southwest of Howland Flat. Infection was found to be common the next day at the 5,500 foot level directly east of Howland Flat. Tentative estimates made by Dr. E. A. Steinhaus and Dr. C. G. Thompson, Department of Biological Control, University of California, who were visiting the area on July 20th, indicated mortality due to infection among 4th, 5th and 6th or prepupal instars in excess of 50 percent. Estimates in all infested areas regardless of infestation intensity on July 28, 1953, revealed that larval mortality was in excess of 90 percent, and indicated a certain end of the epidemic. This occurred all within a period of 2 weeks.

Identification of the disease was established by Thompson soon after discovery, as a polyhedrosis virus. A quantity of infected larvae was processed for virus preservation at the Biological Control Laboratory, University of California, for possible use in the control of future outbreaks.

Meanwhile, examinations of epidemic sawfly infestations in Yosemite National Park revealed similar infections, with populations of larvae nearly all dead. Specimens turned over to Thompson contained the same virus showing that it had become established there, a distance of 160 miles south of the Howland Flat study area. The coincident infection in these remotely separated areas suggests the possibility of latent infection, although this is disputed by the biological control specialists.

The characteristic effect of this virus on infected larvae can be described as follows: The bodies become limp, placid, soft; the color changes to a dirty brownish-gray; within a few days they exhibit noted shrivelling. Affected larvae also reverse normal orientation on the needle, with the head toward the base rather than toward the apex, and there is no feeding. (Photo 8.)

Evidence of virus infection in late July among cocooned prepupal larvae was shown by the limp, placid bodies removed from cocoons. This was substantiated positively in November 1953 by Thompson who examined specimens taken from the field late in October and reported virus bodies. Among 46 cocoons examined in the October collection, 25 or 54 percent of them contained dead, shrivelled larvae.

Weather

What effect weather may have had in exerting a control effect, directly or indirectly, was in no way evident at the beginning of the 1953 season. The great numbers of eggs which had overwintered were nearly all viable and the numbers of early stage larvae were out in epidemic force. The influence of climate. therefore,up to the beginning of the 1953 season, was not important.

Seasonal temperature and/or humidity in 1953 may have acted as an indirect influence on the development of virus infection. This is indicated from records of these factors which show changes during the infection period that may be significant. The possibility of such a tie in depends on latent infection, which as mentioned, has not been demonstrated by the biological control specialists.

An examination of the temperature-humidity record for July 1953, may shed some light on this question. The July record is illustrated by the line chart, Figure 1, which shows daily maximum-minimum temperatures and average percent humidity. The most significant change to take place for a period of 10 days, from July 11 to 20, was a rise in humidity. This rise amounted to a daily average of 20 percent compared to the previous 10-day daily average, and nearly the same for the prior 10-day period, following which there was a drop back to the earlier level. The increase in the humidity level was also accompanied by considerable cloudiness and thunderhead formation for the 10-day period. Afternoon storms occurred throughout the mountainous areas at elevations generally higher than the study area, but no precipitation fell in the immediate zone.

Speculation on the indirect influence of increased humidity during July on larval mortality is based on the sudden and universal incidence of the virus infection. No perceptible difference in infection rate or virulence was noted in any area regardless of infestation intensity, distance, or time of infection. These circumstances support the belief that the virus may have been present universally in all populations of larvae, remaining dormant until weather conditions adversely affected larval resistance, and subsequently favored the growth and development of the organism.

EFFECT OF DEFOLIATION ON WHITE FIR STAND

Direct Lethal Effect

The total amount of tree mortality among the most severely defoliated stands at the beginning of 1953 was estimated to be about 10 percent of the number of trees affected. The most seriously affected trees were among the more suppressed and intermediate groups, already suffering from the effects of competition in relatively dense stands. Amongst these trees there was no evident new terminal foliage growth by mid-summer, 1953; hence, even though the basal cambium was still alive in some cases, there was little likelihood of recovery. Topkilling, in addition to total kill among the intermediate and suppressed trees, amounted to an estimated 10 to 15 percent.

The net effect of killing and top-killing on heavily defoliated stands, as a whole is not regarded as serious in view of the weakened character of the more suppressed trees. Such killing may even be considered beneficial by thinning out the stands and reducing competition.

It should be pointed out that the mortality and topkilling among trees defoliated in 1952 was probably aggravated by the 1952 mid-summer freeze which killed all new growth foliage. This shock added to the heavy defoliation in 1952, was evidently too severe to permit recovery among many of the more suppressed trees. It is doubtful if either complete tree mortality or topkilling would have been more than a fraction of the amount evident in 1953 if the summer, 1952 freeze had not occurred. The coincidence of such an event with heavy epidemic defoliation at frequent intervals is unlikely. Hence, the evidence is strong that under ordinary circumstances the shock of defoliation alone would not be serious so long as current needles completed growth and remained intact.

Weakening Effect

No general weakening of affected stands as a whole among all vigor and age classes as a result of 3 successive defoliations was revealed. Growth data from 50 increment borings showed some decline among dominants, but not in other vigor classes. Such slowing down as was indicated may have resulted from competition rather than defoliation. The number of borings and character of trees from which they were taken were inadequate for a sound evaluation.

Evidence of weakening as judged from attacks by ambrosia beetles, fir engraver beetles, roundheads, or flatheads was also lacking. Although active *Scolytus* broods were fairly common among non-defoliated stands in the vicinity of sawfly infestations, there was no evidence of attacks by these bark beetles or other insects among the defoliated stands examined.

Increment reduction

As indicated, there was no evidence of immediate reduction in growth on the basis of core samples taken. It is likely, however, that any reduction in growth would be more apt to show up in subsequent years rather than immediately. Hence, it is believed that core samples taken about 5 years hence from defoliated dominant trees relatively free from excessive competition should provide a better basis for evaluating the effect of infestations on increment.

ARTIFICIAL CONTROL EXPERIMENTS

Aerial DDT sprays

The infestation on the Plumas National Forest in the spring, 1953, afforded an unusual opportunity to test the effectiveness of aerial sprays as a possible means of control. Information was unavailable at that time on either the life cycle of the sawfly or on its natural control factors; hence it appeared somewhat ahead of schedule to propose any except a small-scale experiment to demonstrate the possibilities of aerial sprays. DDT was selected as the insecticide most likely to be effective, on the basis of its success elsewhere in controlling eastern sawflies, spruce budworm, and other forest tree defoliators.

Detailed plans for the spraying experiment were set up in cooperation with the Plumas National Forest, as an administrative test early in June 1953. An area of 80 acres was decided on as a minimum size for aerial spray coverage. The spray formulation, figuring one pound of DDT per acre was as follows:

Material	Amount
DDT	80 pounds
Velsicol (AR50)	20 gallons
#2 fuel oil	60 "

The area selected was located along the west slopes of Table Rock, immediately east of Howland Flat. The aircraft consisted of a single-engine Nordyne high-wing cargo plane converted for spraying, with dispersal equipment consisting of two revolving brushes. This plane, owned by the U. S. Forest Service, was piloted by S. C. Ayres and K. V. Benesh. The height of flight above tree top level was between 100 and 200 feet. Markers consisting of crinkled household aluminum foil were placed on the corners of the designated area, and were visible from the air. Spray dispersal was measured on the ground by jump cards placed at designated points prior to flight.

Effectiveness of sprays killing sawfly larvae was determined from counts of dead larvae dropping on 30 X 36-inch muslin catch frames placed at designated points beneath the canopy on treated and untreated areas. This was supplemented by measurements of frass deposited under the two situations for a period of 6 weeks following spray application.

The scheduling of this spray operation against young newly hatched larvae depended on close daily checks of egg hatch to determine when 75 per cent or more of the total hatch had taken place. An unusual delay was encountered due to extended cold weather which retarded development. The date finally scheduled was June 25, 1953. Spray formulation and loading took place at Oroville Municipal Airport between 5:00 and 6:30 a.m. when the loaded plane departed for the spray area. Actual spray applications were completed between 7:00 and 7:30 a.m. at which time air movement was at a minimum, with wind velocity estimated at less than 5 miles per hour.

The amount of spray deposited over the area, as measured by 36 jump cards, showed considerable variation in uniformity, both with respect to number of droplets per unit of area and droplet size. This is attributed to the character of dispersal equipment, which as stated consisted of revolving brushes. However, no portions of the sprayed area were found to have been missed.

The results of this test were excellent as judged from the knock-down of larvae and from subsequent frass deposit in treated and untreated areas. The numbers of dead larvae in catch frames at intervals varying from immediately after spraying to 5 days afterward are shown by Table 3 which follows:

Table 3. Number of Dead Larvae in Treated and Check Areas

Period after spraying	Number of dead larvae: Treated Area (Average 6 frames)	Check area (Average 2 frames)
Immediate	111	0.5
6 hours	71	0.0
24 hours	207	1.0
48 "	31	1.5
120 "	11	0.0

The amount of comparative kill in treated and check areas as here shown was 99 per cent.

Further evidence of the great direct knock-down of larvae within 48 hours of spray application was provided by snow patches within the area which were colored green by dead larval bodies. Actual counts revealed in excess of 10 per square inch.

Frass-drop measurements from the catch frames in treated and check areas, taken each week for a period of 4 weeks after spraying, is revealed by Table 4. This again shows that control effectiveness was nearly 100 per cent.

Table 4. Frass Deposited in Catch Frames in Treated and Check Areas

Date 1953	Days after spraying	Cubic Centimeters of Frass Deposited: Treated Area (total 6 frames)	Check Area (1 frame)
June 30	5	Trace	1.2
July 7	12	"	38.3
" 14	19	"	220.8
" 21	26	0	99.7
" 28	33	0	0.1
		Totals 3.0 (estimate)	360.4

The degree of control as shown by these data and by other observations leaves little doubt as to the effectiveness of this method against the fir sawfly. Its usefulness, however, must be balanced against what may be expected from natural factors, actual economic losses in fir stands, and cost of control operations. As indicated earlier, natural control factors, especially the virus infection, effectively controlled the outbreak during 1953. With natural factors in play, or which may be brought into play through artificial dissemination of preserved natural viruses during the initial phases of an outbreak, it is unlikely that DDT or other aerial sprays would be needed.

The actual cost of this DDT spray operation was well within reason, at about $0.90 per acre, including cost of spray materials and time required from the operating airport and return.

Introduced virus sprays

A test was made early in July to determine the effectiveness of an introduced virus to control the white-fir sawfly. The virus consisted of polyhedra suspensions from the European pine sawfly, Neodiprion sertifer (Geoff.) shipped to Berkeley from the New Haven Forest Insect Laboratory.

This material was turned over to C. G. Thompson, Biological Control Department, University of California, who planned and conducted a field test, supplemented by a laboratory test of infectivity at Berkeley. The field test at Howland Flat consisted of spraying water suspensions on 10 heavily infested trees by means of a 5-gallon pressure sprayer. The laboratory tests at Berkeley consisted of immersing sawfly larvae in a water suspension of the virus.

The results of both field and laboratory tests of this virus against the sawfly were entirely negative. No infections resulted, thus demonstrating that the introduced virus could not be relied on as a possible means of controlling outbreaks of this insect.

ADDITIONAL STUDY REQUIREMENTS

Information still lacking, but needed to round out a thorough understanding of the white-fir sawfly and its control pertains to: (1) certain aspects of seasonal biology; (2) biological control factors, especially disease in relation to climate or other ecological factors, and to the susceptibility of different larval stages; (3) effect of defoliation on white fir stands with respect to increment, and susceptibility to attacks by other insects.

On biology, the principal questions to be answered pertain to the proportion of prepupal larvae in each stage of diapause. While it appears that most of the sawfly population has a one year life cycle, there is no certainty of this. If a large portion of a generation holds over for another year, then the hazards from both ecological and biological factors would place a considerable limitation on the chances of survival to adulthood for this group.

The evident benefit of the native virus infection in controlling epidemic sawfly populations is such that it overshadows the combined effect of all other natural control agencies. Information is needed to gain a more complete understanding of its possibilities against all stages of larvae, of a possible association between fatal infectivity and climatic changes, and of the possibilities of controlling incipient outbreaks through suspension sprays from stored virus material.

While a number of different kinds of predacious and parasitic insect enemies have been found closely associated with sawflies, their individual or combined roles as control factors is unknown; nor is it known to what extent hyperparasitism may offset the effectiveness of these natural enemies.

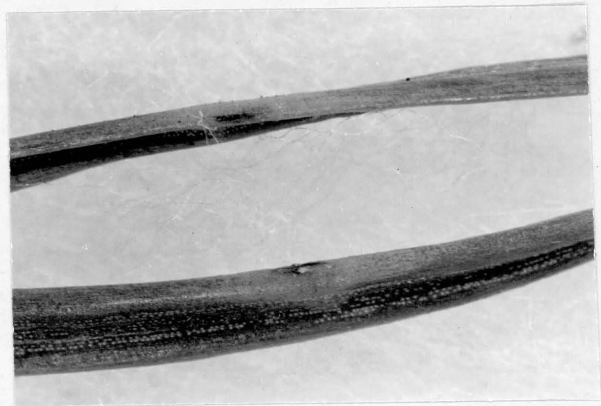
Studies are needed to determine the effect of severe defoliations on a stand of white fir. Losses in increment are undoubtedly sustained for a period, and stand resistance to other insect enemies, especially to barkbeetles, borers, or ambrosia beetles, is probably reduced. Completion of studies on these points in relation to vigor class of trees in affected stands would likely require several years.

Illustrations

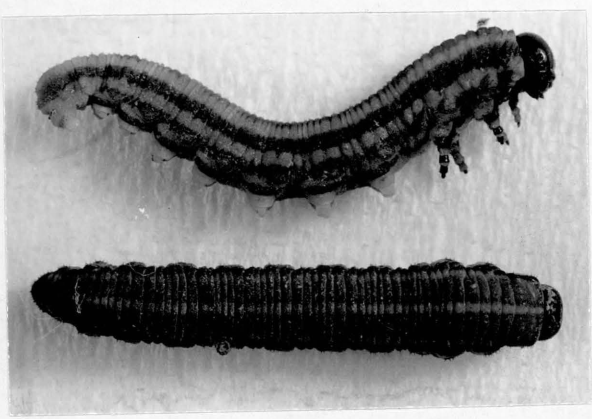
Photo 1. (15735A) Second-growth white fir stands at Howland Flat. Grayish area in left center background is due to heavy defoliations in 1952. Base study camp in foreground. (Original - July 1953)

Photo 2. (15654A) Defoliations during 1952 in contiguous bodies of white fir averaged between 70 and 90 per cent of the crown; complete defoliation as shown here was common. (M. M. Furniss - October 1952)

Figure A. Developmental Stages of the White-Fir Sawfly



1. Egg slits in lateral edge of fir needles, X4. Note crescent-shaped discoloration around slit in lower needle, marking location of egg.



2. Larva (5th instar) X4

3. Cocoon, X4

(Photos by C. B. Eaton - February 1954)

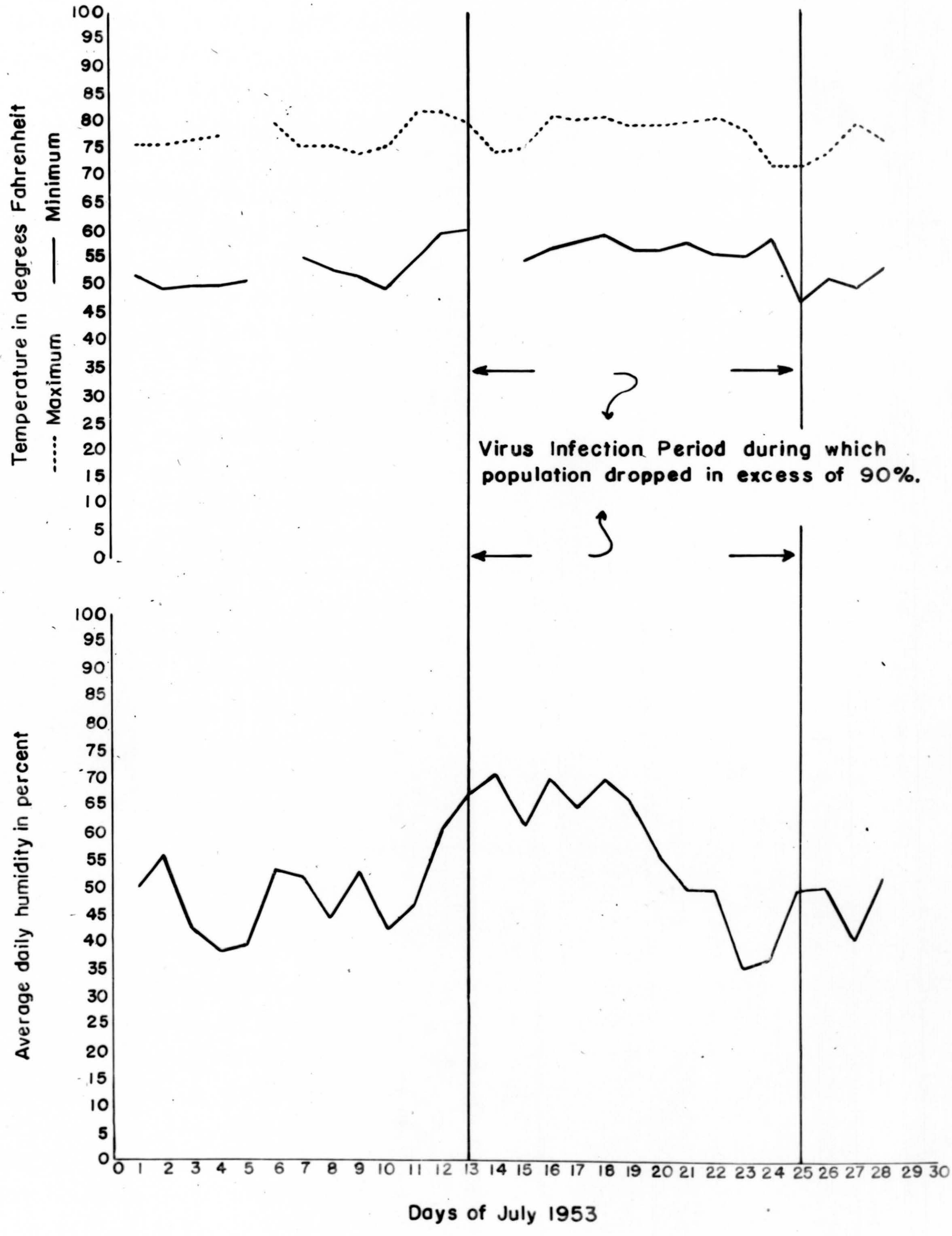
Photo 3. (15735E) Colony of feeding white-fir sawfly larvae, with bead-like heads showing gleaming black. (Original, July 1953)

Photo 4. (15735G) Colony of larvae in typical feeding position, with heads oriented toward apex of needles. (Original, July 1953)

Photo 7. (1573513) Upper crown of white fir 4 weeks after initial feeding by sawfly larvae. This is typical of defoliations in areas defoliated in 1953. Note new terminal growth. (Original, July 1953)

Photo 8. (15375I) Portion of sawfly colony remaining after fatal infection by polyhedrosis virus. Afflicted larvae become placid, shrivel, and orient position with heads oriented toward needle and twig bases. (Original, July 1953)

FIGURE I. Maximum and Minimum temperatures and average daily humidity for the month of July, 1953 and period of insect mortality due to virus.



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